Neutron Magnetic Form Factor

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presentation is based on E09-019 and PR10-007
R.Gilman, B.Quinn, BW

- Neutron structure and EM form factors
- The transverse neutron densities
- Approved GMn experiments at high Q^2
- New proposal for 16&18 GeV^2
- Neutron detection with HCalo

Dirac, Pauli and Sachs Form Factors

Hadron current, one-photon approximation, α_{em} = 1/137, Rosenbluth,1950

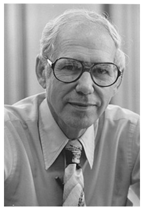
$$\mathcal{J}^{\mu}_{hadron} = ie\bar{N}(p_f)\,[\gamma^{\nu}\underline{F_1(Q^2)} + \frac{i\sigma^{\mu\nu}q_{\nu}}{2\,M}\underline{F_2(Q^2)}]N(p_i)$$

Cross section and asymmetry for electron-nucleon scattering

$$d\sigma = d\sigma_{NS}\left\{(F_1^2 + \frac{Q^2}{4M^2}F_2^2) + (F_1 + F_2)^2\frac{Q^2}{2M^2}(1 + 2\tan^2\frac{\theta_e}{2})\right\}$$

Sachs, 1962

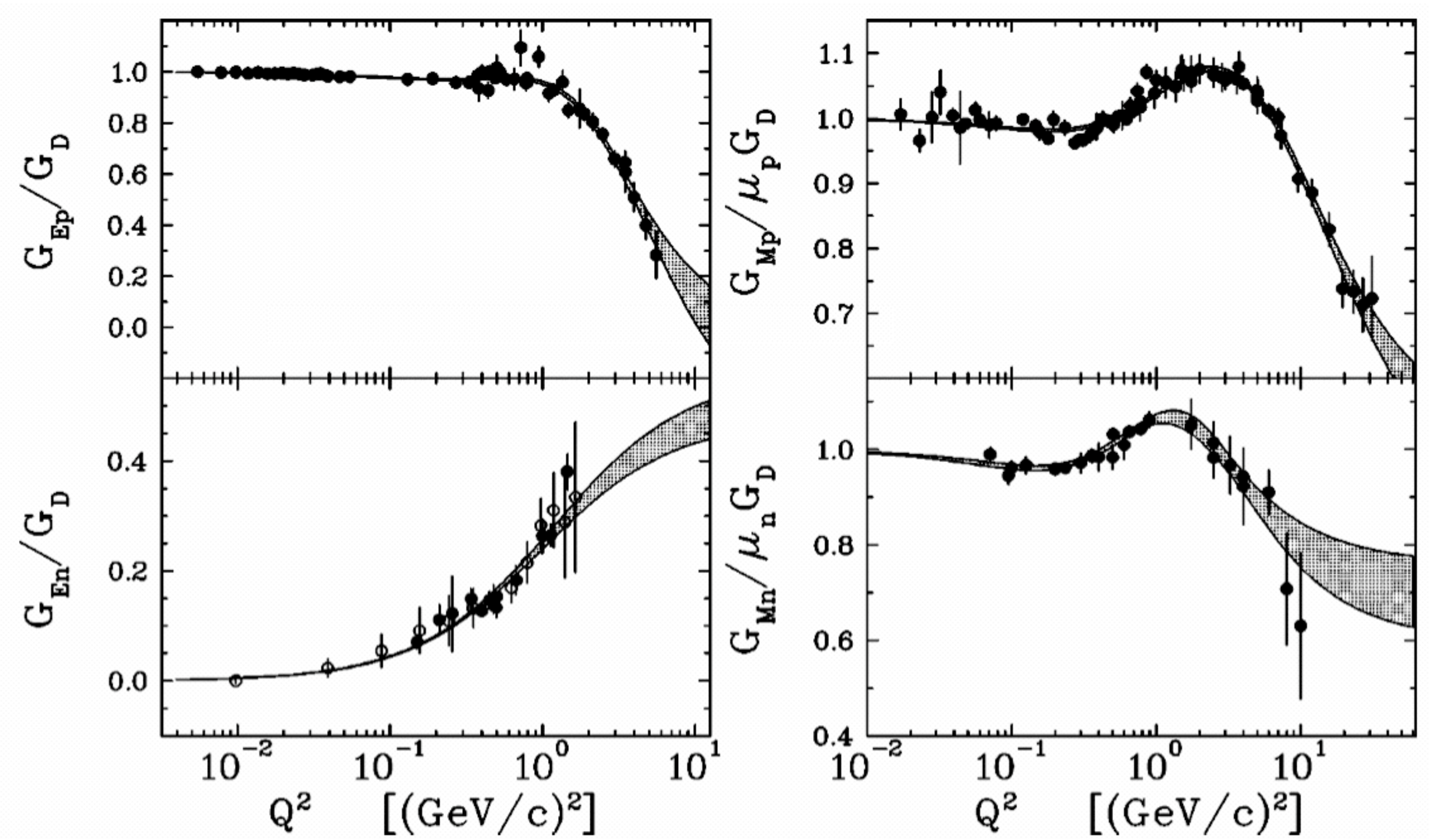
Does a nucleon have a core ?



$$G_E = F_1(Q^2) - \frac{Q^2}{4M^2}F_2(Q^2) \qquad G_M = F_1(Q^2) + F_2(Q^2)$$

$$J_{fi} = 2E \cdot F(-\vec{q}^{\,2}), \quad \vec{J} = 0 \qquad \rho(r) = \frac{1}{(2\pi)^3}\int F(-\vec{q}^{\,2})e^{i\vec{q}\vec{r}}d^3\vec{q}$$

Kelly's parameterization

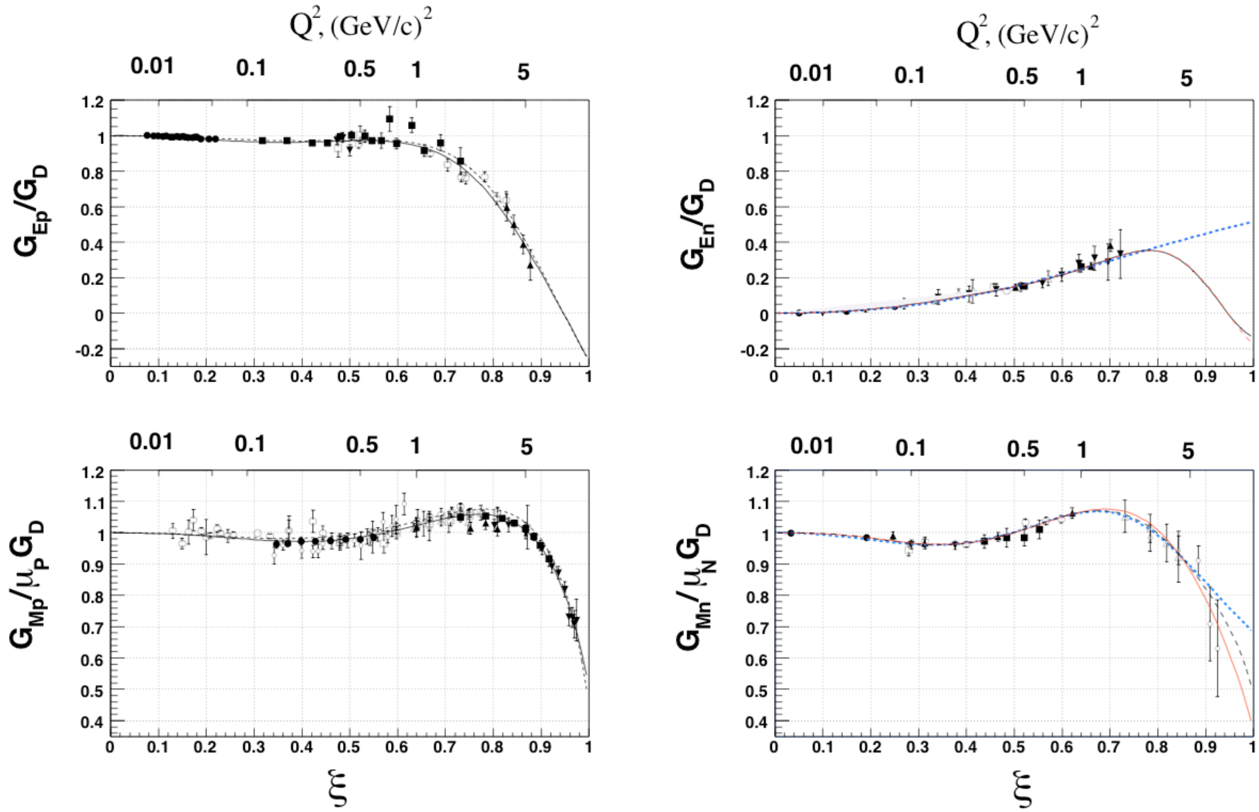


J. Kelly, PRC 70, 068202 (2004)

$$G\left(Q^2\right) = \sum_{k=0}^{n=1} a_k \tau^k / (1 + \sum_{k=1}^{n+2=3} b_k \tau^k)$$

scaling constraint: $Q \to \infty$, $G \sim Q^{-4}$

New parameterization



Bodek, Avvakumov, Bradford, Budd arXiv:hep-ex 0708.1946

ξ is Nachtman scaling variable

Two constraints QCD motivated

Kelly's

(d/u) = 0, 0.2

$$\xi^{p,n} = 2/(1+\sqrt{1+\tau^{-1}_{p,n}})$$

$$G_{BABB} = A(\xi) \times G_{Kelly}(Q^2)$$

$$\text{constrains: at } \xi \rightarrow 1 \quad 1)\ \frac{G^2_{Mn}}{G^2_{Mp}} = \frac{1+4(d/u)}{4+(d/u)} \quad 2)\ \frac{G^2_{En}}{G^2_{Mn}} = \frac{G^2_{Ep}}{G^2_{Mp}}$$

Generalized Parton Distributions

Reduction formulas at $\xi = t = 0$
for DIS and $\xi = 0$ for FFs

$$H^q(x, \xi = 0, t = 0) = q(x)$$

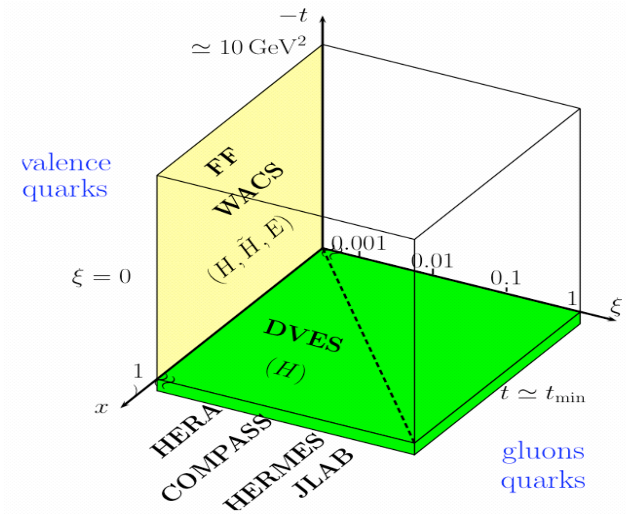
$$\tilde{H}^q(x, \xi = 0, t = 0) = \Delta q(x)$$

$$\int_{-1}^{+1} dx\, H^q(x, 0, Q^2) = F_1^q(Q^2)$$

$$\int_{-1}^{+1} dx\, E^q(x, 0, Q^2) = F_2^q(Q^2)$$

P.Kroll, Excl.-07

a lot to measure



Ji's sum rule for quark orbital momentum

$$\langle L_v^q \rangle = \frac{1}{2} \int_0^1 dx [x E_v^q(x, \xi = 0, t = 0) + x q_v(x) - \Delta q_v(x)]$$

DVCS will access low t, large Q^2 kinematics

FFs presently are the main source for E_v^q

Impact parameter and densities

$$F_1(t) = \sum_q e_q \int dx H_q(x,t)$$

Muller, Ji, Radyushkin

$$q(x,\mathrm{b}) = \int \frac{d^2q}{(2\pi)^2} e^{i\,\mathrm{q}\cdot\mathrm{b}} H_q(x, t = -\mathrm{q}^2)$$

M.Burkardt

$$\rho(b) \equiv \sum_q e_q \int dx\; q(x,\mathrm{b}) = \int d^2q F_1(\mathrm{q}^2) e^{i\,\mathrm{q}\cdot\mathrm{b}}$$

P.Kroll: u/d segregation

$$\rho(b) = \int_0^\infty \frac{Q\cdot dQ}{2\pi} J_0(Qb) \frac{G_E(Q^2)+\tau G_M(Q^2)}{1+\tau}$$

G.Miller

center of momentum $R_\perp = \sum_i x_i \cdot r_{\perp,i}$

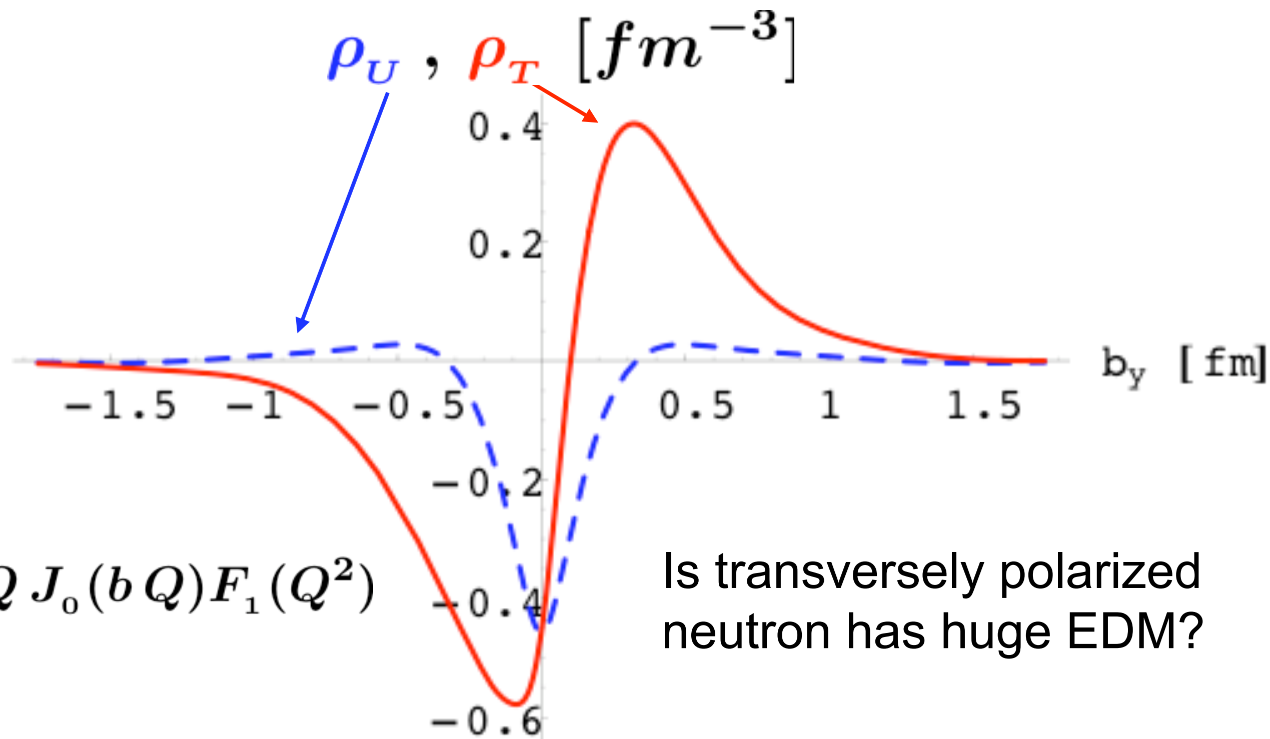
b is defined relative to $R_\perp$

Transverse densities

$$\rho_T(\vec{b}) \;=\; \rho_U(b) \;-\; \sin(\phi_b - \phi_S) \int_0^\infty \frac{dQ}{2\pi}\frac{Q^2}{2M} J_1(b\,Q) F_2(Q^2)$$

C.Carlson &

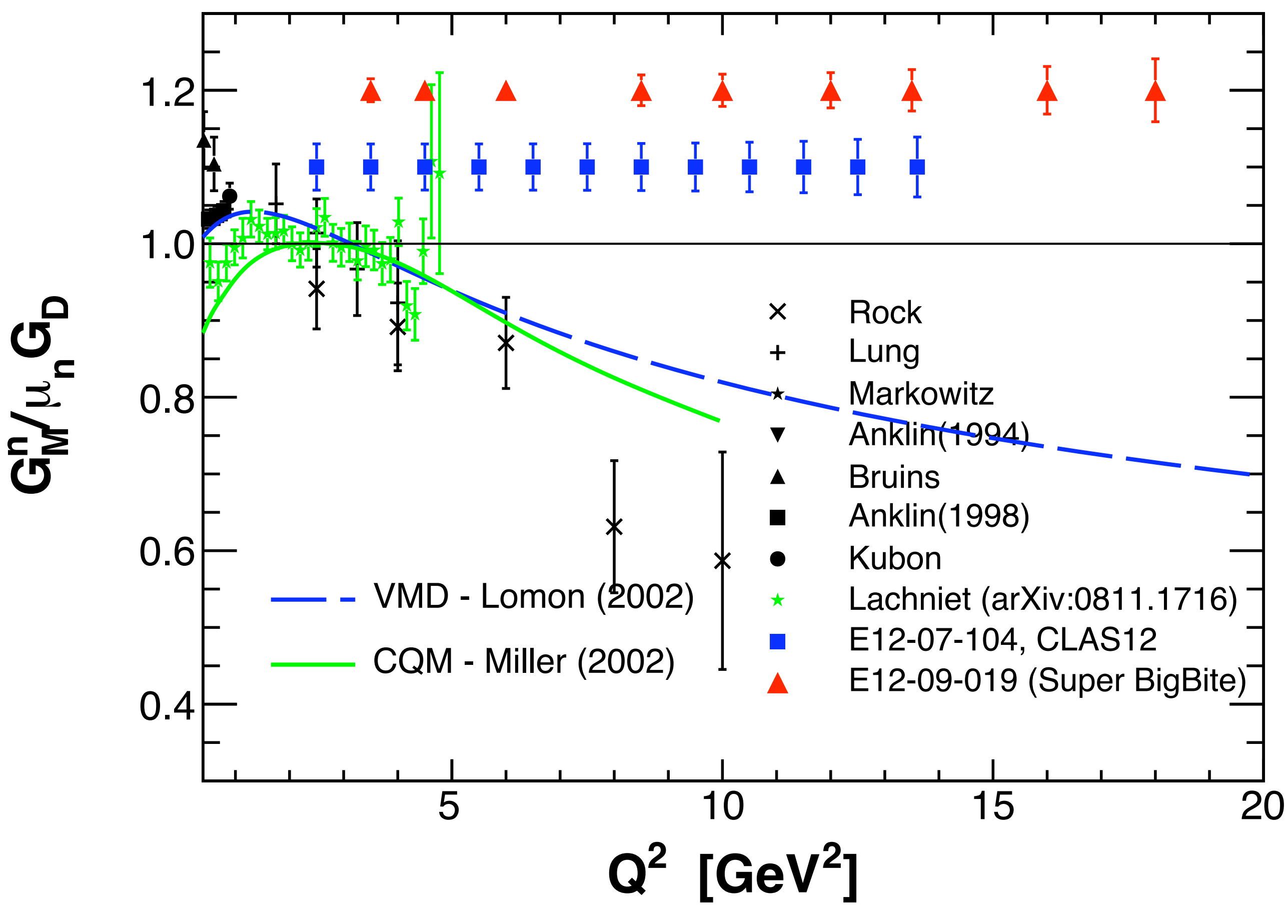
M.Vaderhaeghen



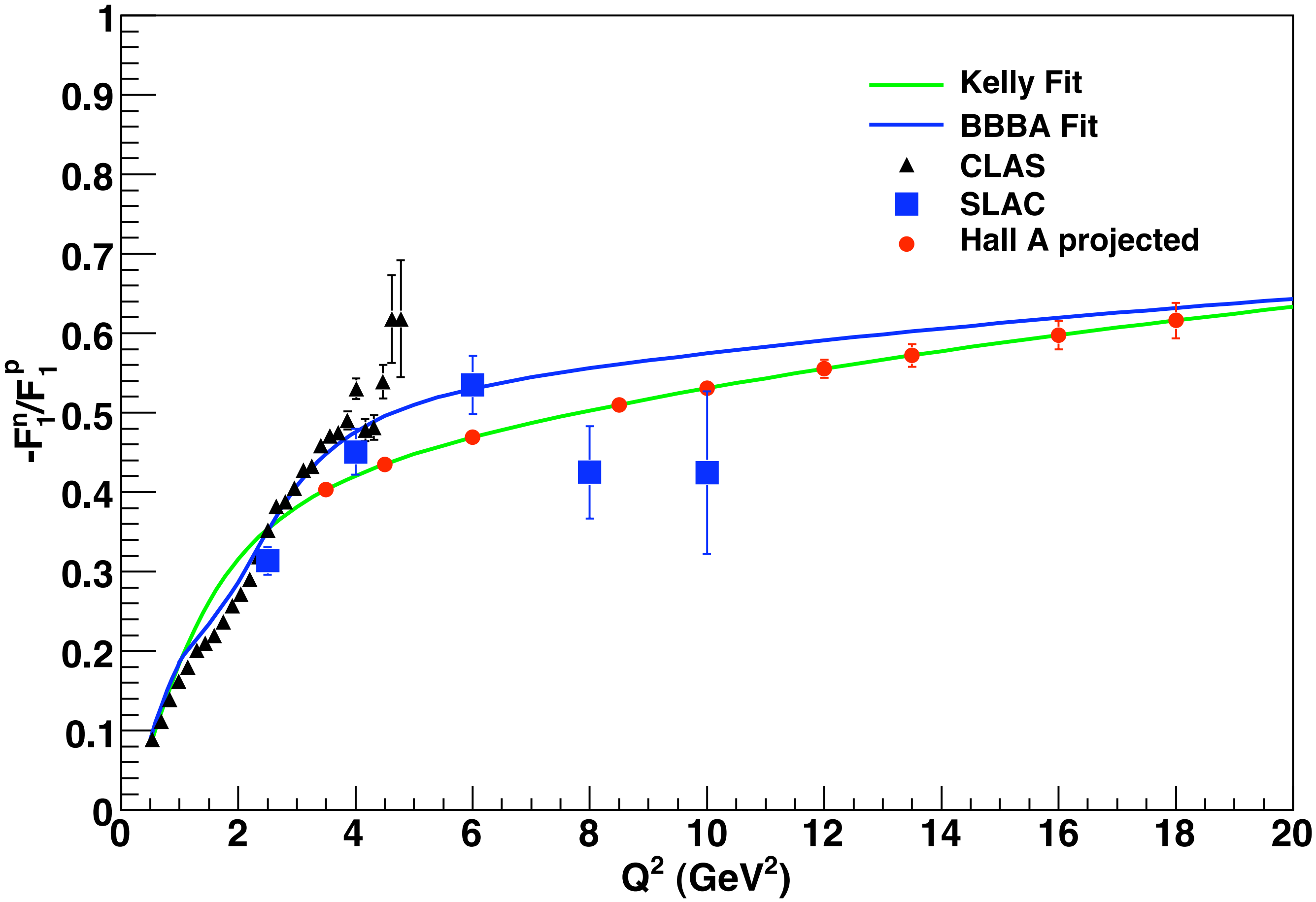
$$\rho_U(b) = \int_0^\infty \frac{dQ}{2\pi} Q\, J_0(b\,Q) F_1(Q^2)$$

Is transversely polarized neutron has huge EDM?

GMn form factor at high Q^2

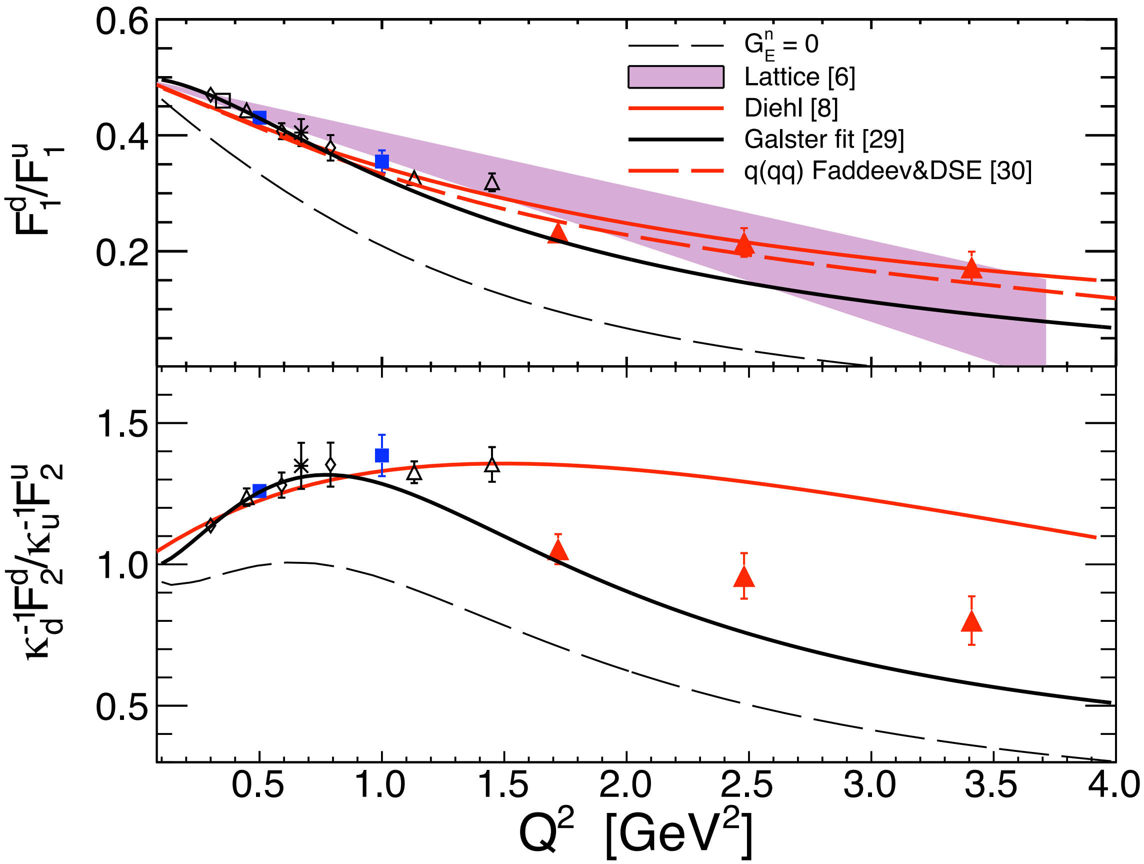


F_1^n/F_1^p form-factor ratio



$F_{1,2}^d/F_{1,2}^u$ form-factor ratio

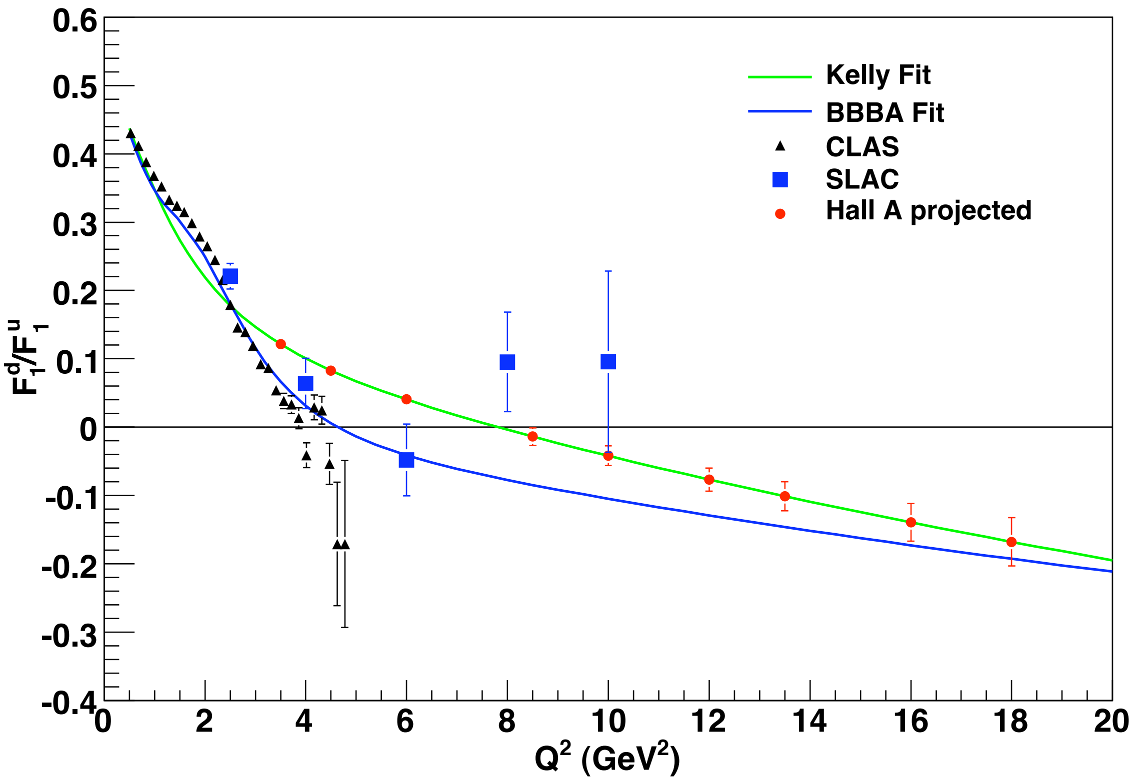
The u and d quarks contributions to the proton form factors



F_1^d/F_1^u form-factor ratio

Use well known FF fits

Is a node in F_1^d ?

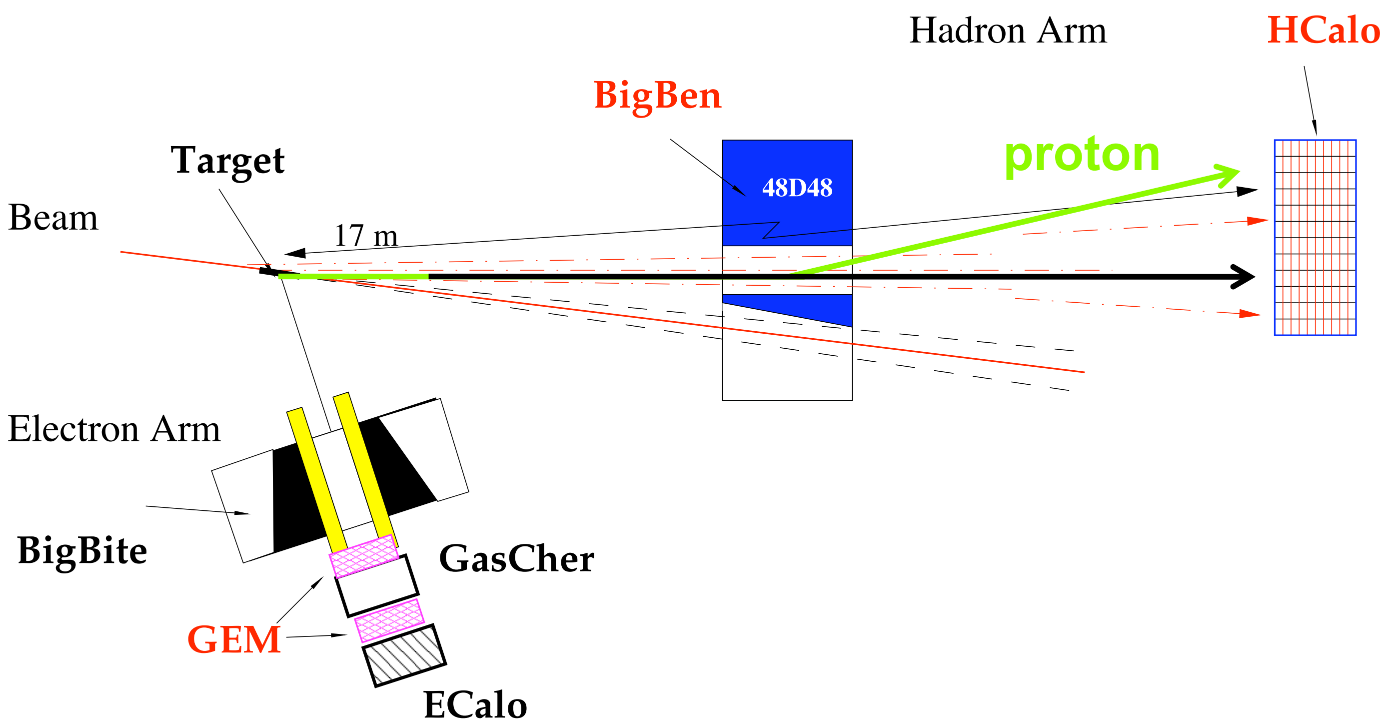


Concept of the GMn experiment

R.Gilman, B.Quinn & BW

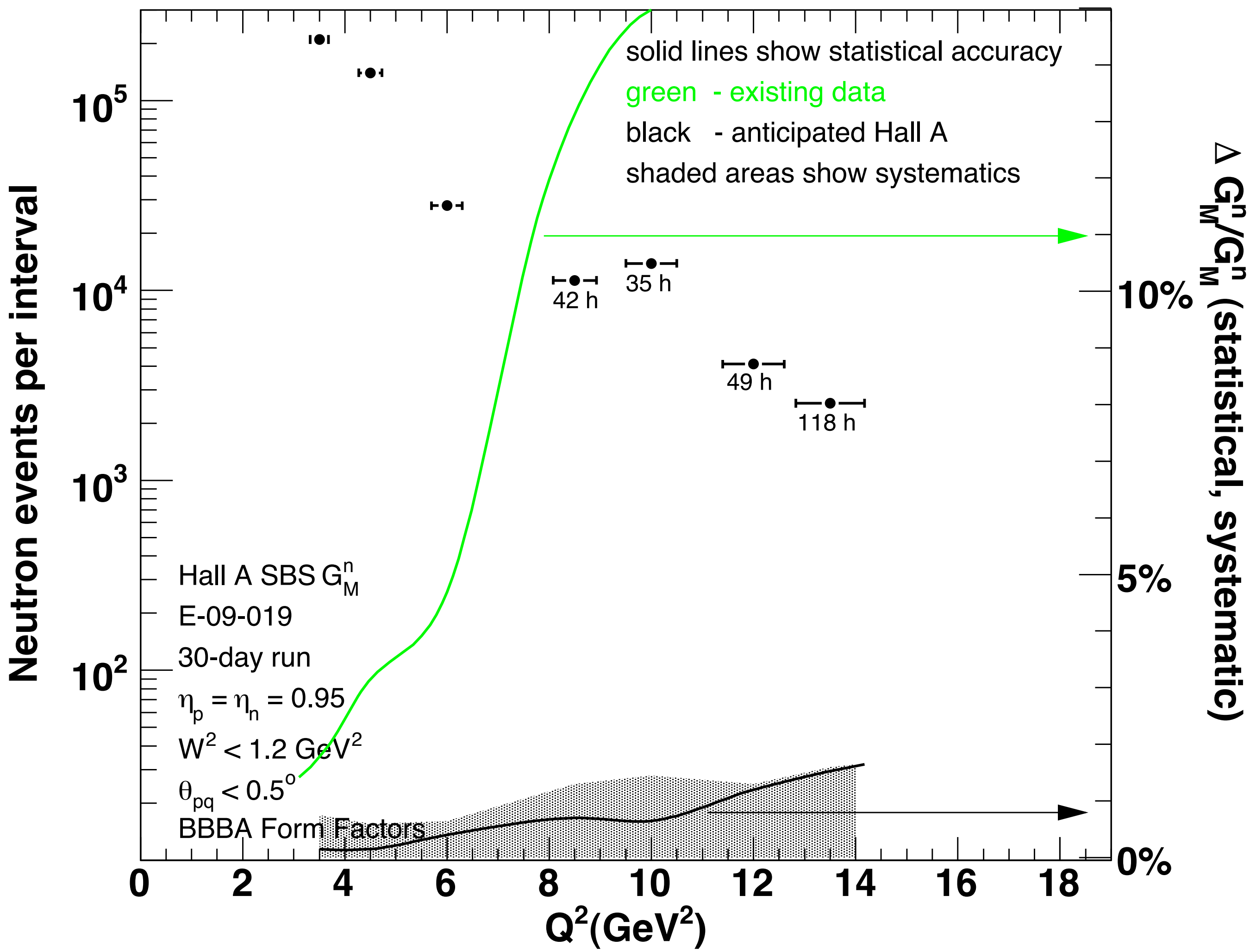
$D(e,e'p)$ and $D(e,e'n)$

Neutron Magnetic Form Factor at Q^2 = 18 GeV ^{2}

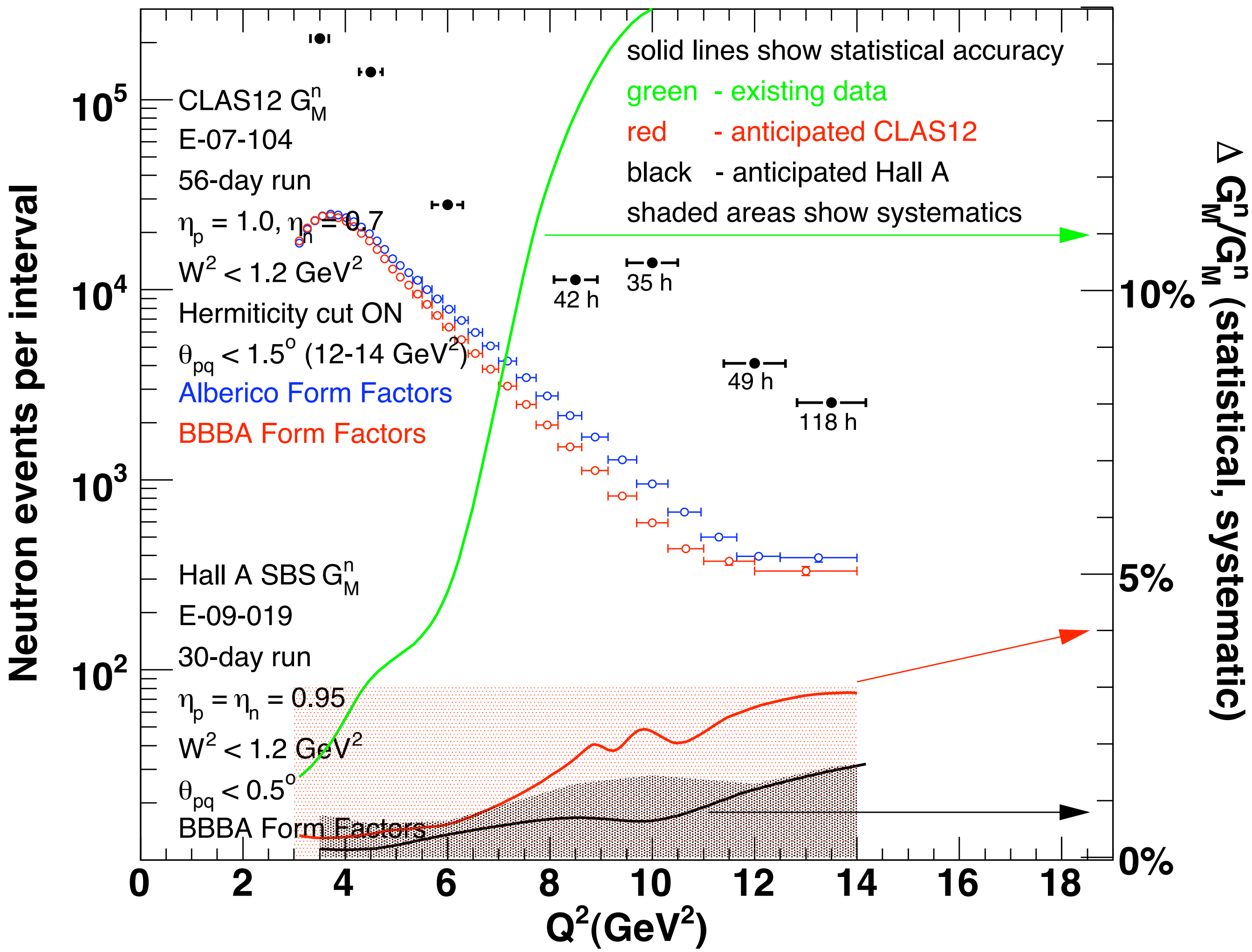


$$R \equiv \frac{d\sigma}{d\Omega}|_n \,/\, \frac{d\sigma}{d\Omega}|_p \rightarrow \frac{\epsilon \cdot (G_E^n)^2 + \tau \cdot (G_M^n)^2}{\epsilon \cdot (G_E^p)^2 + \tau \cdot (G_M^p)^2} \approx \left[\frac{G_M^n}{G_M^p}\right]^2$$

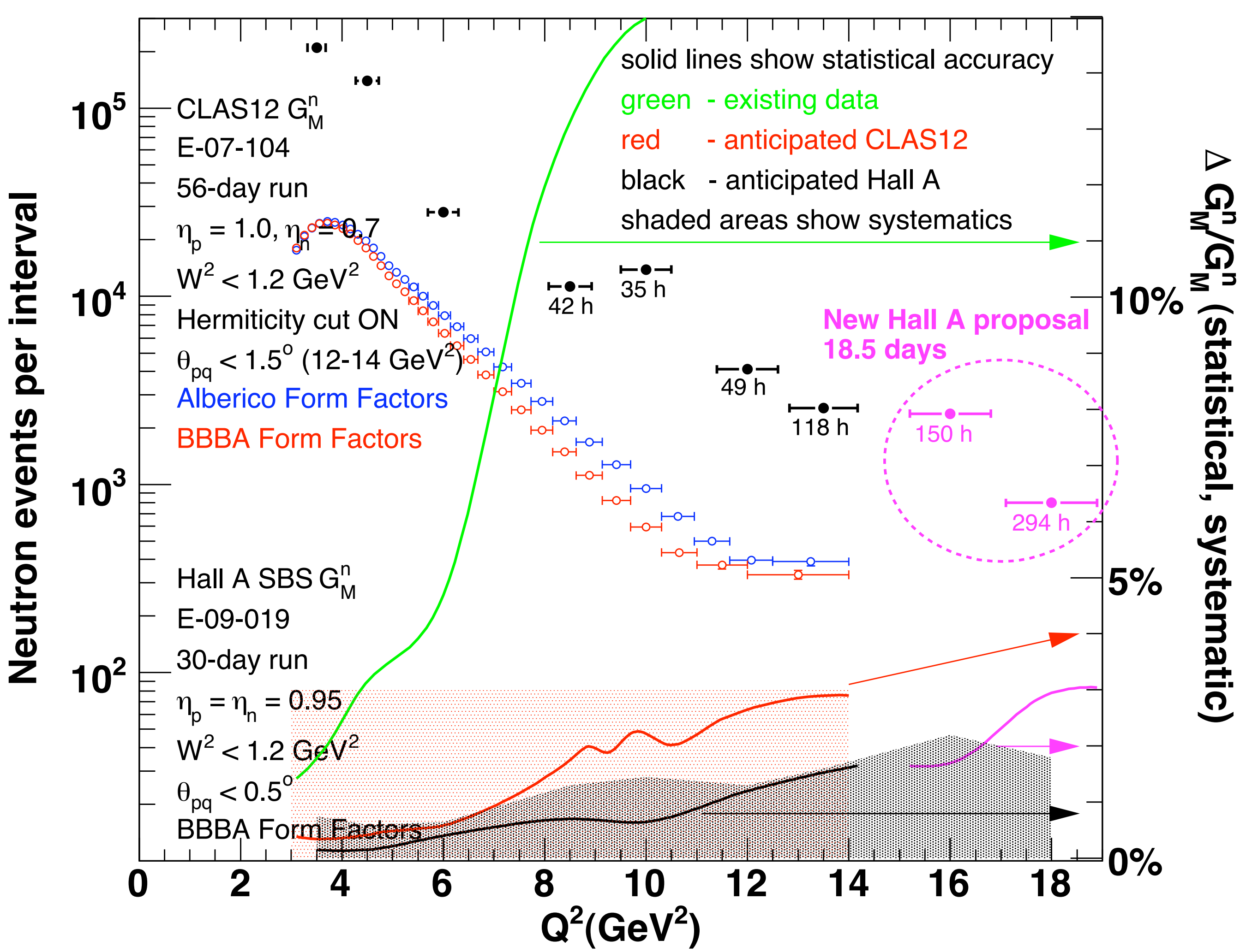
GMN/GMP at high Q^2



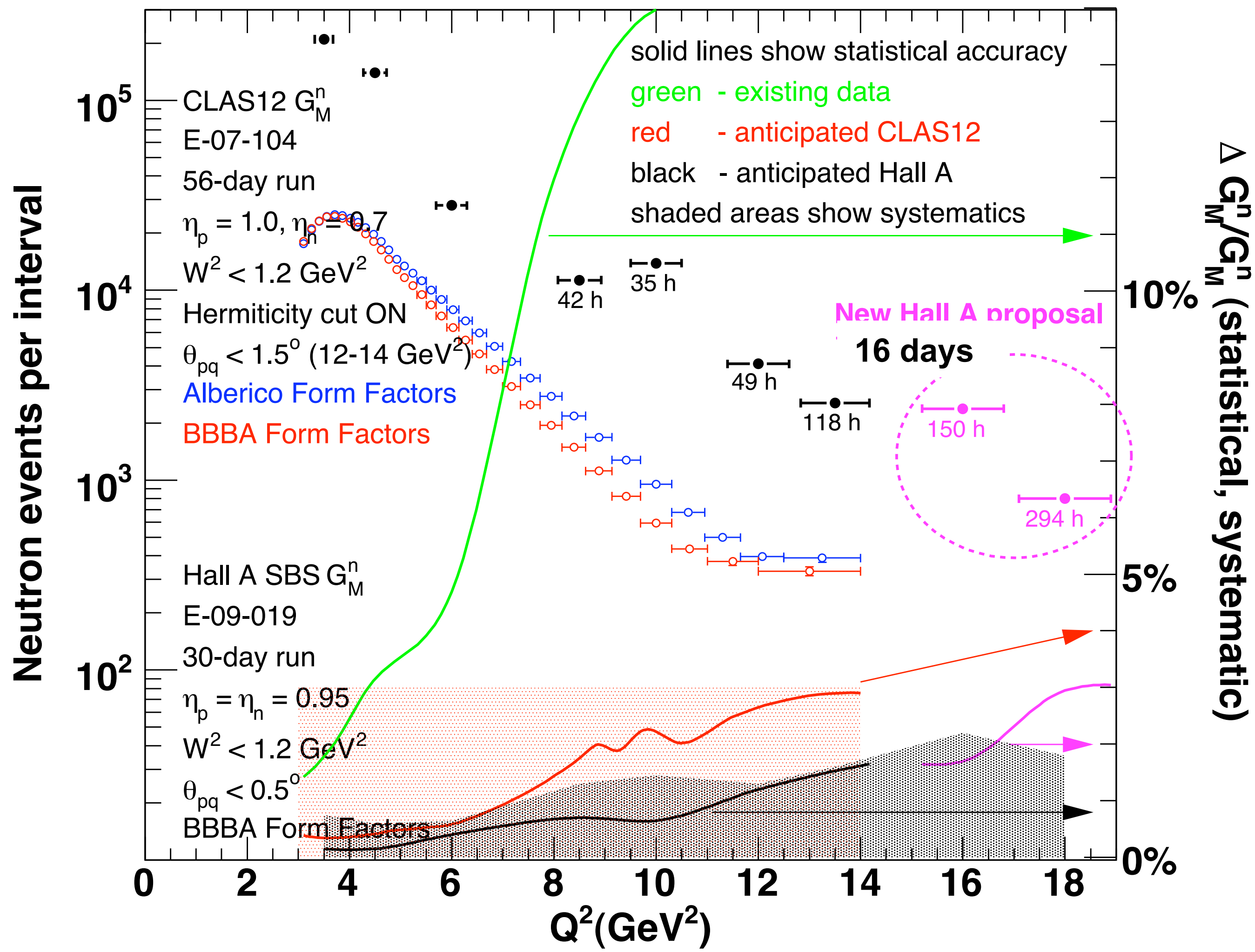
GMN/GMP at high Q^2



GMN/GMP at high Q^2



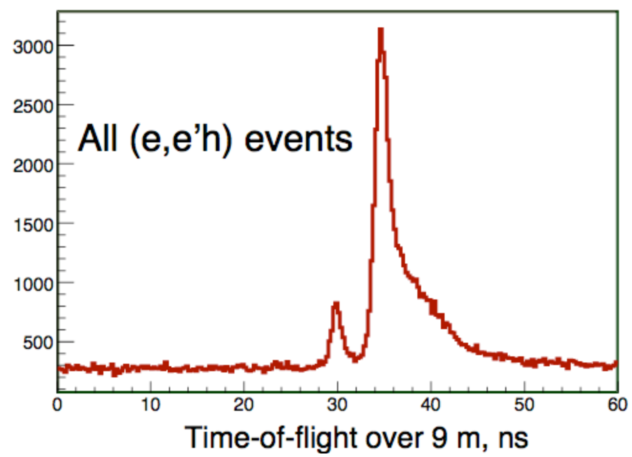
GMN/GMP at high Q^2



Neutron Detector BigHAND

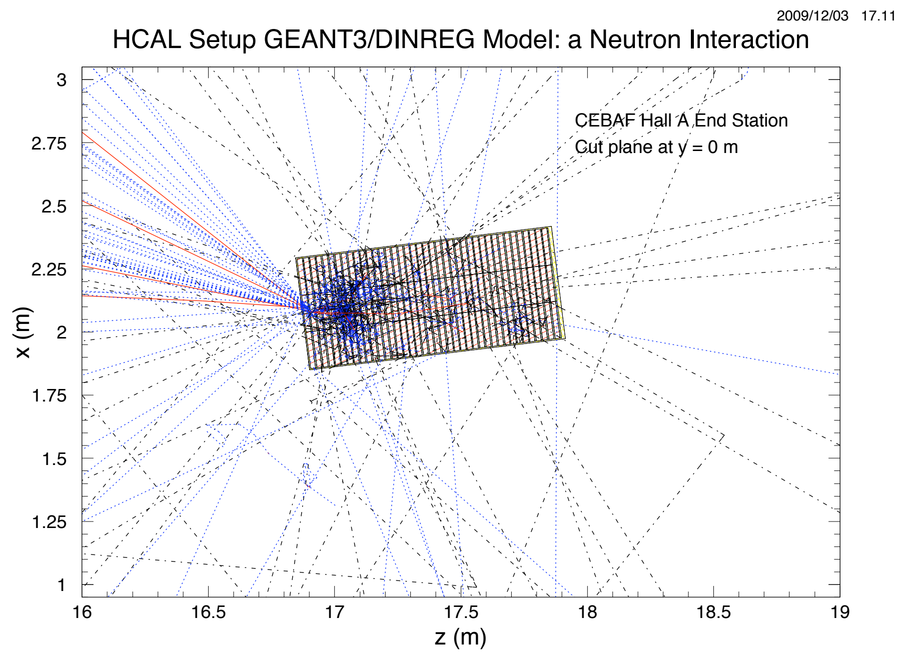
- Match BigBite solid angle for QE kinematics
- Flight distance ~ 10 m
- Operation at $3 \cdot 10^{37}$ cm^2/s

- 1.6 x 5 m^2 active area
- 6-7 layers (~ 250 bars)
- 2 veto layers (~ 200)
- 0.38 ns time resolution



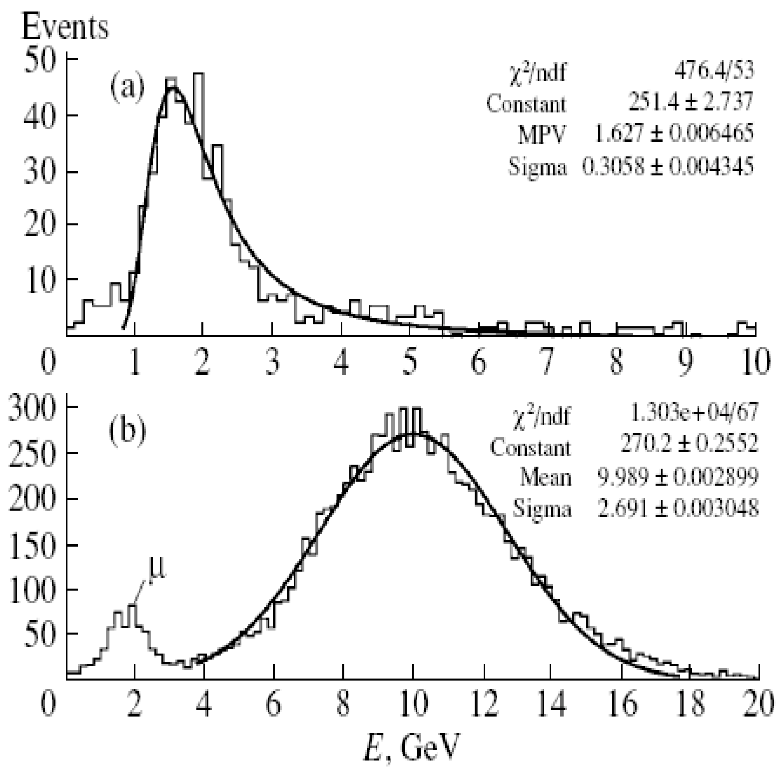
Neutron Detector HCalo

- Match BigBite solid angle for QE kinematics
- Flight distance ~ 17 m
- Operation at $3{\cdot}10^{38}$ cm^2/s



- 5.4 m^2 active area
- 1 layer (250 bars)
- Magnet for n/p ID
- < 1.5 ns time resolution

Neutron Detector HCalo



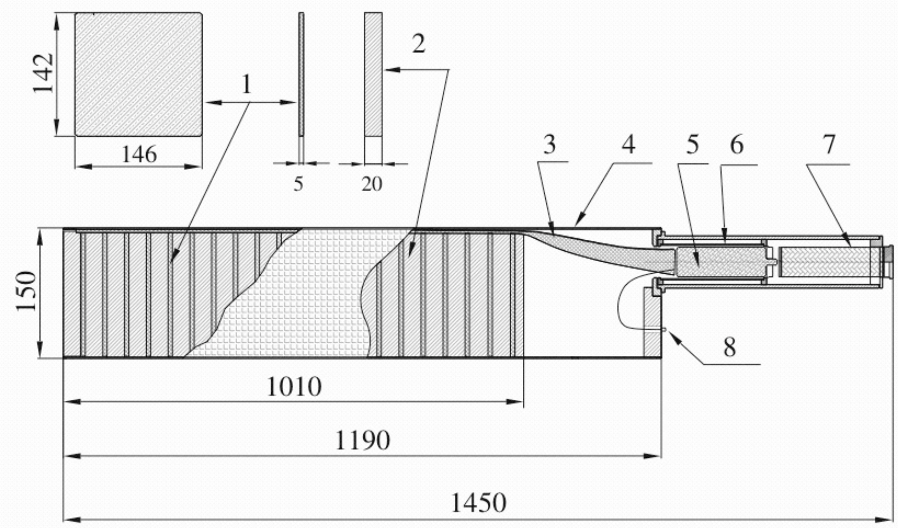


Fig. 48. Structure of the HCAL1 module: 1, scintillators; 2, iron plates; 3, light guide; 4, container; 5, PMT; 6, PMT magnetic shielding; 7, Cockcroft–Walton divider; 8, optical connector for LED control. Dimensions are in mm.

Neutron Detector HCalo

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- Operation at $3 \cdot 10^{38}$ cm^2/s

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- Magnet for n/p ID
- < 1.5 ns time resolution

Neutrons

E[GeV]	2.5	5.0	7.5	10.0
A[MeV]	21	55	94	135
σ_A [MeV]	10	17	25	30
$< A/2$ [%]	11.14	4.71	3.29	2.81
$< A/4$ [%]	2.67	0.80	0.89	0.87
σ_x (gaus)[cm]	2.77	2.19	1.81	1.56
σ_x (mean quad.)[cm]	3.67	2.73	2.13	1.81

Protons

E[GeV]	2.5	5.0	7.5	10.0
A[MeV]	20	55	93	135
σ_A [MeV]	8	17	24	30
$< A/2$ [%]	7.60	3.62	2.89	2.60
$< A/4$ [%]	1.19	0.40	0.62	1.01
σ_x (gaus)[cm]	2.24	2.01	1.80	1.55
σ_x (mean quad.)[cm]	3.28	2.58	2.17	1.83

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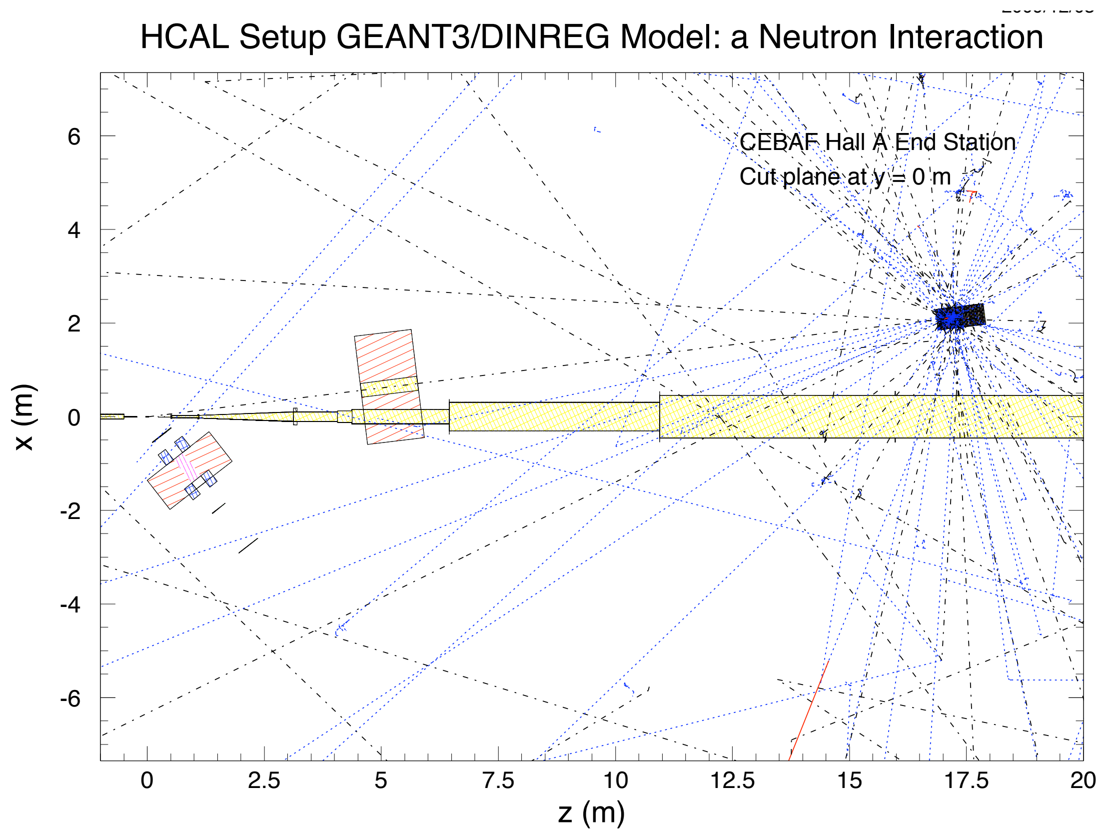

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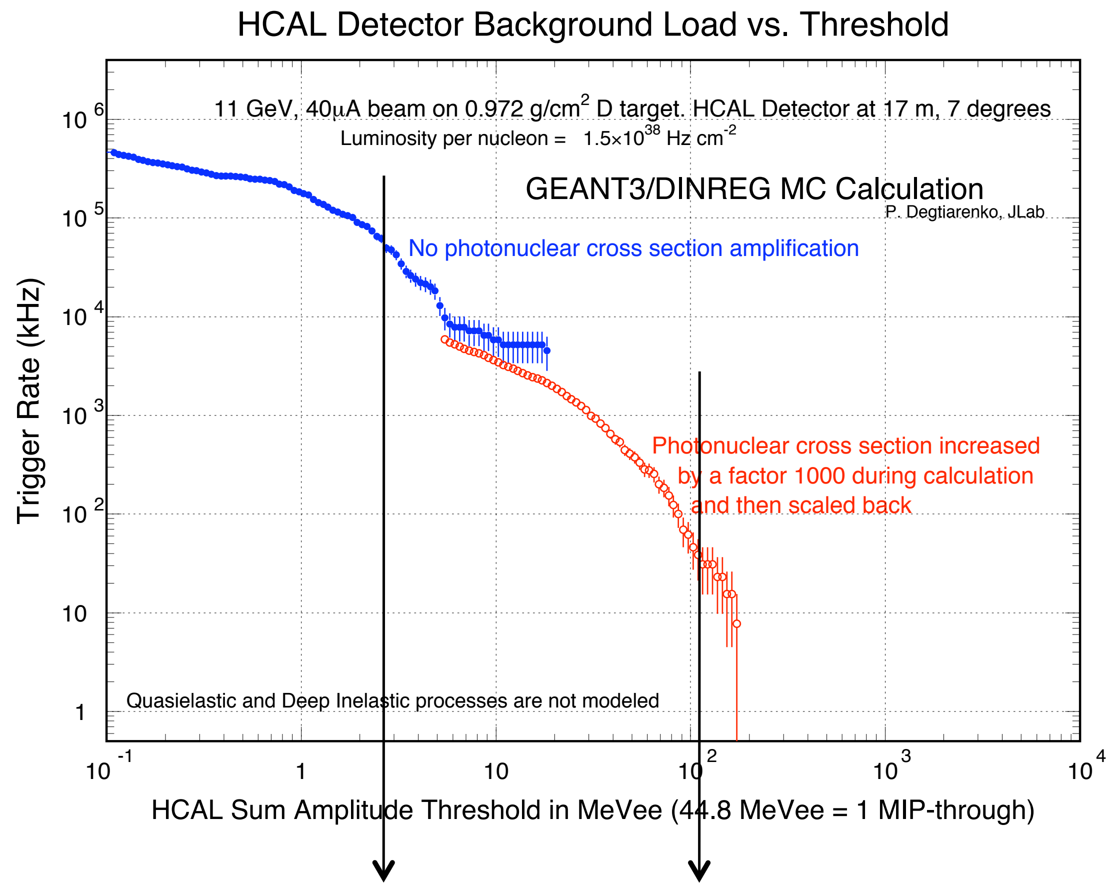

BigHNAD threshold HCalo threshold

- $5.4\ m^2$ active area
- 1 layer (250 bars)
- Magnet for n/p ID
- < 1.5 ns time resolution